TITLE **Defining the parameters for endovenous microwave ablation to achieve equivalence with endovenous laser ablation, using the porcine liver model.**

Authors: Anjali Bachetta (ORCID: 0000-0002-8401-3508)

Simon Cheung (ORCID: 0000-0002-0986-5030)

Emma R Moore (ORCID: 0000-0001-9986-2310)

Danny Nguyen (ORCID: 0000-0002-1028-3767)

Melissa J Kiely BSc (ORCID: 0000-0002-8663-6127)

Mark S Whiteley MS FRCS(Gen) (ORCID: 0000-0001-6727-6245)

Institution: The Whiteley Clinic, Stirling House, Stirling Road, Guildford, Surrey GU2 7RF

Correspondence: Prof M S Whiteley MS FRCS(Gen), The Whiteley Clinic, Stirling House, Stirling Road, Guildford, Surrey GU2 7RF

E-mail: mark@thewhiteleyclinic.co.uk

Tel: +44 (0)330 058 1850

Fax: +44 (0) 1483 477194

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ABSTRACT

Aims: Endovenous microwave ablation (EMWA) is a relatively new catheter-based endovenous thermoablation (EVTA) system to ablate incompetent truncal veins. Early results suggest that EMWA uses more power than endovenous laser ablation (EVLA) to get the same results. Therefore, we aimed to define the parameters for EMWA, which give the same tissue ablation as EVLA, using the previously validated porcine liver model.

Methods: EVLA (1470nm and 600micron radial fibre) treatments were performed at 6W, 8W and 10W, at each pullback speed of 6, 7, 8 and 9 s/cm, giving a range of Linear Endovenous Energy Densities (LEEDs) between 36 – 90 J/cm. We repeated each combination of power and pullback five times. Following a preliminary screening process to identify parameters that gave similar results, we used EMWA in the same model. Powers of 35-75W and pullback speeds of 4-9 s/cm were used (LEEDs 140-675 J/cm). Ablation tracts from both devices were analysed by two blinded observers, noting thermal spread and carbonisation.

Results: For each of the commonly used parameters for EVLA, we identified a range of power and pullback parameters for EMWA that produced similar tissue ablation in the porcine liver model. To keep the pullback speeds within the usual range, we used powers of 35-75W with EMWA, with mean EMWA LEEDs 3.9 - 5.8 times higher than EVLA LEEDs. We found the quicker the pullback speed, the higher the multiple of EMWA LEED we needed to get the same effect.

Conclusion: We have identified parameters for EMWA that gave equivalent tissue ablation in the validated porcine liver model to commonly used parameters and LEEDs for EVLA. As the power during EMWA is higher than EVLA, EVMA LEEDs are approximately 4-6 times higher than EVLA LEEDs to achieve the same thermal effect on the tissues.

INTRODUCTION

Endovenous thermal ablation (EVTA) is the first line recommended treatment for truncal vein reflux causing symptomatic varicose veins (including bleeding and superficial venous thrombosis) or fascio-cutaneous damage in the lower leg (up to, and including, venous ulceration).[1-3]

The most widely used methods of EVTA are radiofrequency ablation (RFA) and endovenous laser ablation (EVLA). Endovenous microwave ablation (EMWA) is a relatively new catheter-based EVTA system. Although reasonable ablation rates have been reported, the power parameters currently used vary widely, from 20W-65W. [4-8]

Doctors working with EVLA report the energy used for ablation as the Linear Endovenous Energy Density (LEED)[9] - the energy used per cm of vein treated. However, the wide variation of power and pullback combinations reported by those using EMWA have not included the LEED,[4-8,] making comparing devices and reported outcomes challenging.

For those wishing to use EMWA to emulate their EVLA practice, there is no independent comparison between the two methods to suggest which EMWA parameters will give the same ablation results as the EVLA parameters they currently use.

This study aims to use the validated porcine liver model to define which parameters for EMWA emulate the effects of the most commonly used parameters for EVLA.

METHODS

The porcine liver model has been described and validated previously.[10-13] The previously described protocol for assessment of thermal spread and the blinding of the observers using this model was followed.[14] Figure 1 shows the porcine liver model in use.

The fresh porcine liver was acquired from a local butcher and allowed to reach room temperature (21°C) before the experiment commenced. First, the liver was placed on a plastic sheet and covered with 0.9% normal saline solution. Next, the laser fibre or microwave antenna was placed on the liver's serosal surface and covered with heat-resistant glass (30x10cm). Clamps held the glass with sufficient pressure to push the device into the liver, always ensuring contact with the porcine liver serosa on three sides. This pressure is essential for observation of the lateral thermal spread through the glass. Finally, we removed any air bubbles by irrigation with 0.9% normal saline using a plastic cannula and syringe.

A high-resolution digital camera (Nikon D90) was positioned on a tripod to take digital images. Each image also included a ruler placed on the glass and a code number representing the parameters used. Including these allowed for accurate measurements to be made later from the digital image and assessment of the ablation tract by blinded observers, unaware of the parameters used.

The EVLA system selected for the comparison was the Vari-Lase 1470nm diode laser (Teleflex, Wayne, Pennsylvania, United States) with a 600-micron radial fibre. Five ablation tracts, each 3cm long, were made at 6W, 8W and 10W using pullback speeds of 6, 7, 8 and 9 cm/s. These combinations gave ablation tracts in the porcine liver model correlating to LEEDS between 36J/cm and 90J/cm at the three different powers tested. An experienced venous surgeon (MSW) performed the treatments as a continuous pullback.

We then performed a preliminary trial using the ECO-100E2 catheter (ECO, Nanjing, Jiangsu, P. R. China) using powers ranging from 30-80W and various pullback speeds (4-9 s/cm, to identify adequate ablation tracts which had the potential to correlate with those formed using EVLA.

We identified that using pullback times of 4-9 s/cm (corresponding closely to those used with EVLA), the ablation tracts that appeared most similar to those produced by EVLA were made using EMWA power settings between 35-75W. Using this information, we then performed five ablations in the porcine liver model, each 3cm long, with EMWA at each combination of powers 35, 40, 45, 50, 55, 60, 65, 70 and 75W and with pullback speeds of 4, 5, 6, 7, 8 and 9 cm/s. We performed the treatments using an interrupted pullback technique. The catheter was held still during the heating phase, and when the heating cycle had finished, the device was withdrawn 1cm and the process repeated.

The digital images for the EVLA and EMWA were cropped, straightened, and anonymised with a unique code for each image for blinded analysis by two observers. These observers had not been involved in performing the ablations or the image preparation.

The thermal spread was assessed on each digital image using SketchAndCalc™ (v: 6.2.4) (https://www.sketchandcalc.com/). As porcine liver changes colour from a deep purple/brown to light beige when the protein is denatured by heat, the observers were able to assess the lateral extent of the thermal ablation for each treatment – the thermal spread. The two blinded observers made five measurements per image - maximum lateral spread, minimum lateral spread and three random lateral spreads. The observers were instructed not to make any measurements within 3 mm of either end of the ablation tracts. This restriction avoided the inclusion of any artefacts due to the beginning or end of the ablation. They also recorded any carbonisation using the scale noted in Table 1.

Each observer made measurements of the total lateral spread of the ablated tissue in mm to 2 decimal places (0.01 mm). As mentioned above, there were five measurements for each image. We combined the results from each observer, resulting in ten measurements of lateral thermal spread per image. Results from each of the EVLA parameters were compared to those from each EMWA parameters, using a one-way ANOVA with Tukey's multiple comparison tests (GraphPad Prism 9 - https://www.graphpad.com/scientific-software/prism/).

Once we had identified those EMWA ablation tracts that produced equivalent lateral thermal spreads to the EVLA tracts, we analysed carbonisation. The blinded observers graded each ablation tract using the scale in Table 1. Ablation tracts with a mean carbonisation score of 2.5 or more were considered to show excess carbonisation.

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RESULTS

The results are tabulated in Table 2.

For each of the selected EVLA parameters studied, at least one EMWA combination of parameters produced very similar results. For example, to achieve similar thermal effects as EVLA with a LEED of 48 J/cm at 8W power, the same lateral thermal spread can be achieved by EMWA using:

- 35W 7 s/cm
- **35W *8 s/cm***
- 40W 6 s/cm
- ***40W 7 s/cm***

However, we found excessive carbonisation of 2 of these parameters, leaving either 35W at 7 s/cm or 40W at 6 s/cm as optimal (Figure 2).

Similarly, to achieve an equivalent effect as obtained with EVLA with a LEED of 64 J/cm at a power of 8W, we have found EMWA with the following parameters to produce similar results:

- 35W 9 s/cm (>0.9999)
- ***40W 8 s/cm (0.9711)***
- 45W 7 s/cm (0.9644)
- 45W 8 s/cm (>0.9999)
- 45W 9 s/cm (>0.9999)

- 50W 6 s/cm (0.9001)
- 55W 5 s/cm (0.9997)
- ***60W 6 s/cm (0.9993)***
- ***75W 4 s/cm (>0.9999)***

Once again, to choose the optimal parameters, we can remove those causing excessive carbonisation and those with p values of less than 0.99. Making these changes leaves us with a choice of:

- 35W 9 s/cm (>0.9999)
- 45W 8 s/cm (>0.9999)
- 45W 9 s/cm (>0.9999)
- 55W 5 s/cm (0.9997)

The higher power with a faster pullback - 55W at 5 s/cm (Figure 3) - would be the most appealing, although all of these produced the same results.

We thought there might be a simple conversion from the LEED obtained with EVLA and that produced with EMWA, which would make selecting the optimal parameters easy. However, we found that the mean EMWA LEEDs varied their relationship with EVLA LEEDs depending on the speed of pullback of the EVLA device (Figure 4).

At all 3 EVLA powers tested, the EMWA LEED needed to attain the same result was higher in proportion with the quicker pullbacks and lower with the slower ones. However, we could not find a trend with the increasing EVLA power.

DISCUSSION

EVTA requires transmural death of the vein wall for successful long-term ablation by fibrosis.[15,16] The porcine liver model, with its ability to measure thermal spread from an EVTA device, has proven very useful in assessing such devices, both RFA and EVLA,[10,13,14] and has been shown to correlate well both histologically with ex-vivo great saphenous vein[11] as well as with clinical results.[12]

As such, we have produced a table of parameters that doctors might refer to when using the ECO EMWA device to attain an equivalent treatment they would achieve with their preferred setting with the Vari-lase 1470nm radial fibre.

Although this should be useful clinically, it does raise some interesting issues.

The fact that the power levels of EMWA are so different from EVLA to get the same thermal effect in the porcine liver model suggests that the power displayed on the console is not the same as the energy emerging from the tip of the device. An alternative conclusion would be that the microwave field at the device's tip causes less heat generation for the same power, but this is less likely.

In the EU, regulations allow laser consoles to have an error of +/- 20% from the displayed power.[17,18] Furthermore, the power displayed on laser consoles is a measurement of the electrical input into the diode that produces the laser, not its output.

Hence there is a loss of energy from several points between the electrical input into the diode and the emission of laser energy from the fibre tip, including the diode itself (especially if cold),[19] optical couplings, and from the fibre itself – lateral energy loss, impurities in the fibre material and back reflection from the tip.[20]

Such differences might explain why one meta-analysis concluded that "commonly used parameters" are not important in EVLA.[21] However, the authors used papers with "acceptable" ablation rates of around 92% and did not consider that the papers used reported outcomes from different EVLA systems. One would reasonably expect far better outcomes if optimal parameters were generated for each different EVLA system and modified for the size of the vein treated – both the diameter and the vein wall (ie: the mass of tissue to be ablated).

The relationship between the power displayed on the microwave console and the energy emerging from the EMWA device tip is less well studied. However, it is likely that the power displayed on the console is a measurement of the electrical input into the system. Losses will occur before the energy reaches the microwave antenna. Indeed, it is noticeable that during use, the endovenous catheter for the ECO microwave system heats up significantly, indicating power loss along the catheter.

Furthermore, in the published literature, at least 2 different companies are making EMWA devices.[4-8] It is quite possible that the power displayed and the amount of energy emerging from the device tip might vary between the manufacturers. This might explain why such a wide range of powers have been reported for treating varicose veins with EMWA.

There are several limitations of this study. The first and most obvious is that we have used an in vitro model. Even though the porcine liver model has been used previously and validated clinically, conclusions derived from an in vitro study still need to be verified in clinical practice.

Secondly, we have only used one EMWA system and one EVLA system. As such, the results apply to those systems, but must be checked if other EMWA or EVLA systems are used.

Thirdly, the interrupted pullback method we used for the EMWA resulted in a less homogeneous tract, giving noticeable differences between the maximum and minimum lateral thermal spreads. Therefore, a continuous pullback might give slightly different results. However, using a continuous pullback method introduces another variable into the system, making it easier for inexperienced doctors to use the interrupted technique.

In conclusion, we have used the validated porcine liver model to define the optimal parameters (power and pullback speed) to use with EMWA, to emulate the most commonly used parameters for EVLA. We have confirmed that EMWA requires a higher power than EVLA to get the same thermal effect in porcine liver tissue and found that the LEED for EMWA is approximately 4-6 times higher than that for EVLA. However, the difference between the LEEDs for EMWA and EVLA is not constant. It seems to be related to the speed of pullback of the EVLA rather than the power.

CONTRIBUTIONS

Conception or design of the work - MS Whiteley

Data collection - A Bachetta, S Cheung, ER Moore, D Nguyen, MJ Kiely

Data analysis and interpretation - A Bachetta, S Cheung, ER Moore, D Nguyen, MJ Kiely, MS Whiteley

Drafting the article - A Bachetta, S Cheung, ER Moore, D Nguyen, MJ Kiely

Critical revision of the article - MS Whiteley

Final approval of the version to be published - A Bachetta, S Cheung, ER Moore, D Nguyen, MJ Kiely, MS Whiteley

DECLARATIONS

No declarations relevant

CONFLICTING INTERESTS

None

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ETHICAL APPROVAL

Not relevant

GUARANTOR

Prof Mark S Whiteley

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LEGENDS

Figure 1: Photograph of the porcine liver model set-up.

Figure 2: Example ablation tracts from the porcine liver model [A] Radial EVLA LEED 48 J/cm at 8W [B] EMWA 35W with 7 s/cm pullback [C] EMWA 40W with 6 s/cm pullback.

Figure 3: Example ablation tracts from the porcine liver model [A] Radial EVLA LEED 64 J/cm at 8W [B] EMWA 55W with 5 s/cm pullback

Figure 4: A graph showing how the EMWA LEED varies against the EVLA LEED and how this decreases with longer EVLA pullback time across all EVLA powers studied. The X-axis is the EVLA pullback in s/cm, and the Y-axis is the multiple of EVLA LEED found for the equivalent EMWA LEED (see text).

Table 1: The carbonisation scale used to assess carbonisation in the ablation tracts.

Table 2: This table shows the EMWA parameters that have equivalent ablation tracts to the EVLA parameters studied. The EMWA parameters in ***bold italics*** are those with excessive carbonisation (mean of 2.5 or more – see text).